

ORIGINAL RESEARCH

ANKLE DORSIFLEXION RANGE OF MOTION
INFLUENCES DYNAMIC BALANCE IN INDIVIDUALS
WITH CHRONIC ANKLE INSTABILITYCurtis R. Basnett, PT, DPT, ATC¹Michael J. Hanish, PT, DPT²Todd J. Wheeler, PT, DPT³Daniel J. Miriovsky, PT, DPT, ATC³Erin L. Danielson, PT, DPT⁴J.B. Barr, PT, DPT, OCS¹Terry L. Grindstaff, PT, PhD, ATC, SCS, CSCS¹

ABSTRACT

Purpose/Background: Individuals with chronic ankle instability (CAI) often have impairments in ankle range of motion (ROM) and balance. There is limited evidence that these impairments are related in individuals with CAI. The purpose of this study was to determine the relationship between ankle dorsiflexion ROM and dynamic balance in individuals with CAI.

Methods: Forty-five participants (age = 23.2 ± 2.8 y, height = 172.1 ± 10.8 cm, mass = 70.6 ± 13.3 kg, Foot and Ankle Ability Measure Sport = 71.2 ± 11.7 , Modified Ankle Instability Instrument = 6.4 ± 1.3) volunteered for this study. Ankle dorsiflexion ROM was measured in a weight-bearing position while dynamic balance was measured using the Star Excursion Balance Test (SEBT) in the anterior, posteromedial, and posterolateral directions. Linear regression was used to determine the relationship between ankle dorsiflexion ROM and measures of dynamic balance.

Results: There were fair positive correlations between dorsiflexion ROM and the anterior reach direction ($r = .55$, $r^2 = .31$, $P < .001$), posterolateral reach direction ($r = .29$, $r^2 = .09$, $P = .03$), and the composite SEBT scores ($r = .30$, $r^2 = .09$, $P = .02$). There was little or no relationship between ankle dorsiflexion and the posteromedial reach direction ($r = .01$, $r^2 = .001$, $P = .47$).

Conclusions: Ankle dorsiflexion ROM can influence dynamic balance, specifically the anterior reach portion of the SEBT.

Clinical Relevance: Individuals with CAI who demonstrate impairments in dorsiflexion ROM may also demonstrate difficulty with portions of the SEBT. Clinicians may use this information to better optimize rehabilitation programs that address ankle dorsiflexion ROM and dynamic balance.

Keywords: Ankle sprain, functional ankle instability, postural control

Level of Evidence: 5

¹ Creighton University, Omaha, NE, USA

² Capitol Orthopaedics & Rehabilitation, Rockville, MD, USA

³ Spooner Physical Therapy, Scottsdale, AZ, USA

⁴ Advanced Physical Therapy, Anchorage, AK, USA

Study approval was granted by the Institutional Review Board at Creighton University. This study was supported by a grant from the Sports Section of the American Physical Therapy Association. This trial was registered on ClinicalTrials.gov (NCT01423513).

Note: Basnett, Hanish, Wheeler were all DPT students at the time of the study. Miriovsky and Danielson were Orthopedic Physical Therapy Residents.

CORRESPONDING AUTHOR

Terry L. Grindstaff, PT, PhD, ATC, SCS, CSCS
Creighton University, School of Pharmacy &
Health Professions, Physical Therapy
Department, 500 California Plaza, Omaha,
NE 68178.

E-mail: GrindstaffTL@gmail.com

Phone: 402-280-5674

INTRODUCTION

Lateral ankle sprains are one of the most common lower extremity joint injuries and have a high recurrence rate.¹ The clinical manifestation is pain and decreased function relating to deficits in strength, range of motion (ROM), and dynamic balance that can last for weeks after injury.¹ Rehabilitation programs often address these impairments, but some individuals may continue to demonstrate deficits in ankle dorsiflexion ROM^{2,3} and balance⁴⁻⁶ which may contribute to the high risk of injury recurrence.¹ The repetitive frequency of ankle sprains and associated functional limitations has been described as chronic ankle instability (CAI).² Mechanical (ligamentous) and functional (neuromuscular control) ankle instability can contribute to CAI independently or in combination.^{7,8} Rehabilitation is more likely to address functional ankle instability while surgery can address mechanical laxity.

Impairments in both static and dynamic balance have been shown to be present in individuals with CAI.⁹⁻¹⁵ These deficits are likely due to altered proprioception and neuromuscular control.⁷ Most notably balance deficits are greatest during dynamic activities.¹⁴ A clinical measure of dynamic balance is the Star Excursion Balance Test (SEBT) that requires the individual to maintain balance on a single limb while reaching as far as possible in a predetermined direction with the opposite limb.¹⁶ Greater reach distances are indicative of better dynamic balance and individuals with CAI have been shown to demonstrate reductions in reach distances when compared to their healthy control counterparts.^{4-6,17} Asymmetry between right and left anterior reach distances (>4 cm)¹⁸ and limitations in posterolateral reach distances ($<80\%$ normalized reach distance)¹⁹ have been shown to be risk factors for lateral ankle sprains and may contribute to CAI.

The SEBT requires concurrent mobility and neuromuscular control of the lower extremity in order to achieve maximal reach distances. The ability to utilize available ROM at the hip, knee, and ankle has been shown to have a strong relationship positive relationship with reach distance.^{20,21} Specifically, sagittal hip and knee motion influence the anterior, posteromedial, and posterolateral reach distances,²⁰ while ankle dorsiflexion ROM has been shown to

influence the anterior reach distance in healthy individuals.²¹ Some individuals with CAI have been shown to have a deficit in ankle dorsiflexion ROM^{2,17} which has been shown to translate to dynamic tasks such as jogging²² and dynamic balance.¹⁷ Recently the relationship between ankle dorsiflexion ROM and SEBT reach distances has been explored in individuals with CAI.¹⁷ Hoch et al¹⁷ reported a moderate correlation ($r = 0.47$) between ankle dorsiflexion ROM and the anterior reach component of the SEBT, while there was not a significant correlation between ankle dorsiflexion ROM and the posteromedial ($r = 0.28$) or posterolateral ($r = 0.36$) directions. Although the Hoch et al¹⁷ study begins to provide insight into the relationship between a static measure of ankle dorsiflexion ROM and a dynamic balance measure, the methods used to quantify ankle motion (distance to wall), measured in centimeters may not be easily interpreted by healthcare professionals. The use of an inclinometer that provides a measure of motion in degrees is likely more useful for clinicians to quantify ankle dorsiflexion ROM. The purpose of this study was to determine the relationship between a weight bearing measure of ankle dorsiflexion ROM and SEBT reach distance in the anterior, posterolateral, and posteromedial reach directions as well as the composite SEBT scores in individuals with CAI.

METHODS

Participants

Forty-five participants (12 males; 33 females) with unilateral or bilateral CAI volunteered for this study (Table 1). Participants were recruited from the surrounding university community and metropolitan area, but were not necessarily seeking medical care for ankle pathology. CAI was defined as a history of at least one ankle sprain, repetitive episodes of “giving way”, and diminished self-reported function. Mechanical instability or pathological laxity of the ankle joint (ligamentous testing) was not measured

Table 1. Participant demographics. Values are mean \pm SD.

Age (y)	23.2 \pm 2.8
Height (cm)	172.1 \pm 10.8
Mass (kg)	70.6 \pm 13.3
Modified Ankle Instability Instrument	6.4 \pm 1.3
FAAM Sport (%)	71.2 \pm 11.7
Number of lateral ankle sprains	4.2 \pm 3.5

or quantified. Diminished self-reported function was defined as scoring 85% or less on the Foot and Ankle Ability Measure (FAAM) Sport²³ or at least 3 on the Modified Ankle Instability Instrument (AII).²⁴ In the event participants reported bilateral CAI (31 participants), the limb with the greatest impairment in ankle dorsiflexion ROM was used for data analysis. Exclusion criteria were assessed by using a healthy history form and included any lower extremity injury/surgery (including lateral ankle sprain) within the last 6 months (to avoid influence of acute symptoms), diagnosed ankle osteoarthritis, history of ankle surgery involving intra-articular fixation, or current pregnancy. The study was approved by the Institutional Review Board of Creighton University and all participants signed an informed consent form prior to participation.

Procedures

Each participant completed an informed consent form and was screened to match the above inclusion and exclusion criteria using a standardized health history form and self-reported outcomes forms (FAAM and AII). Once inclusion criteria were met, measures of ankle dorsiflexion ROM and dynamic balance during the SEBT were obtained bilaterally with the participants barefoot, with data from the involved limb used for statistical analysis.

Ankle Dorsiflexion Range of Motion

Ankle dorsiflexion ROM was measured using a digital inclinometer (Acumar Single Digital Inclinometer; Lafayette Instrument Company, Lafayette, IN) during a weight-bearing lunge (Figure 1).²⁵⁻²⁷ The digital inclinometer was aligned with the tibial tuberosity and the anterior tibial crest. The participant was instructed to lunge forward by bending both knees, to dorsiflex the ankle as far as possible, keeping the heel on the floor. The angle of the tibia relative to the floor was used to quantify ankle dorsiflexion ROM. Participants were allowed three practice trials and then performed three trials, with the average used for data analysis. A previous study has shown good reliability ($ICC_{3,1} \geq 0.99$)²⁶ and a low minimal detectable change (1.5°) in individuals with ankle pathology and the authors have demonstrated good reliability ($ICC_{2,3} = 0.96$) and a minimal detectable change of 4° in healthy individuals in their laboratory.²⁸

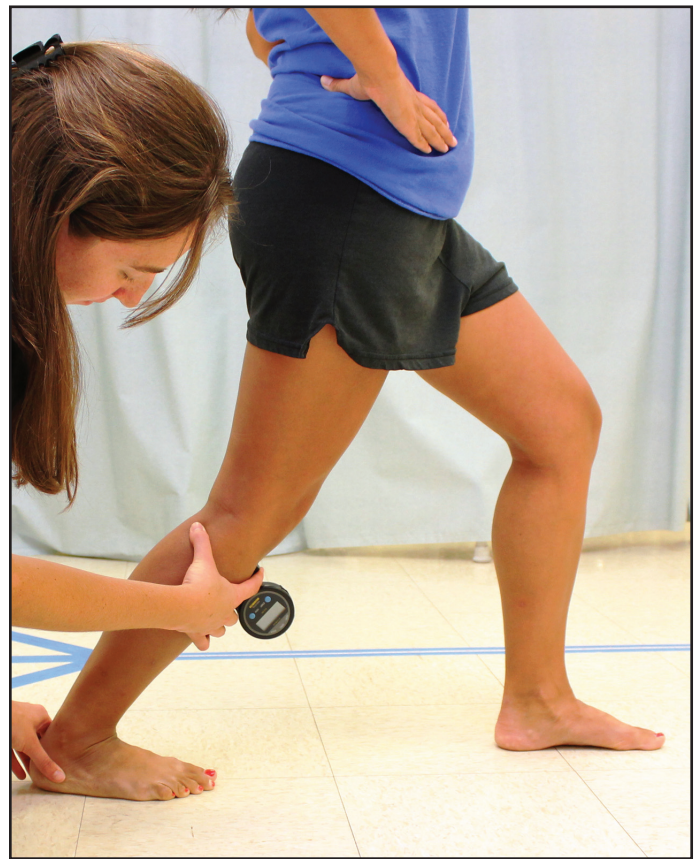


Figure 1. Ankle dorsiflexion range of motion was measured using a weight bearing lunge. The digital inclinometer was aligned with the tibial tuberosity and the anterior tibial crest. The participant was instructed to lunge forward, to dorsiflex the ankle as far as possible, keeping the heel on the floor. The angle of the tibia relative to the floor was used to quantify ankle dorsiflexion ROM.

Star Excursion Balance Test (SEBT)

The SEBT was used as a functional test to quantify dynamic balance. For the current study, participants performed the anterior, posterolateral, and posteromedial reach directions (Figure 2). Participants placed their great toe at the zero point of a tape measure, while the posterolateral and posteromedial directions required the participant to place their heel on the zero point. This foot position was slightly modified from the standard SEBT where the geometric center of the foot is aligned with the intersection of the crosshairs⁶ and was altered in order to better standardize the starting position of the foot. Participants were instructed to reach as far as possible with their contralateral limb in the respective reach direction. Reach distance was quantified as the furthest point the contralateral foot was able to touch on the tape measure while maintaining balance on the test limb and hands

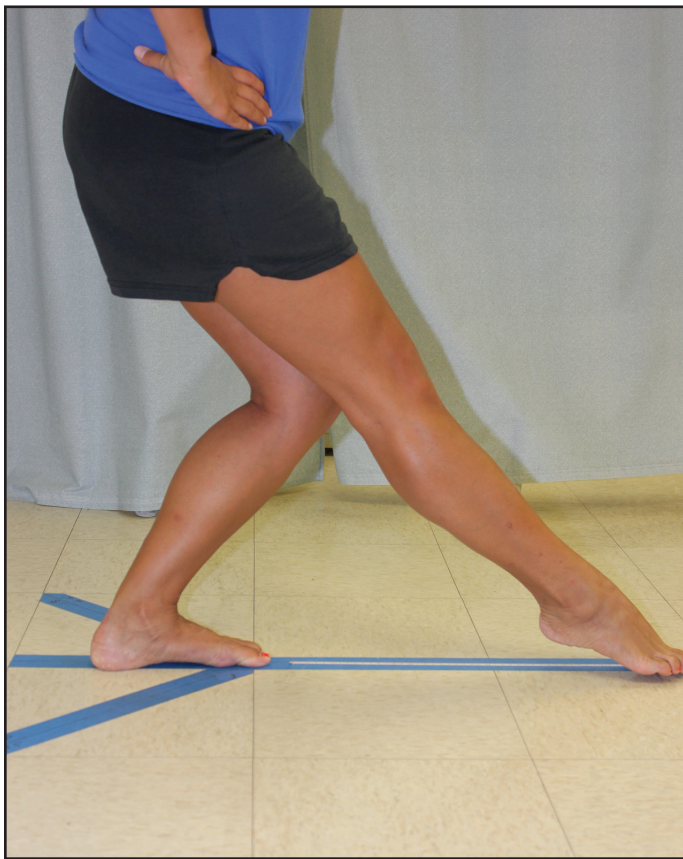


Figure 2. Star Excursion Balance Test was performed in the anterior, posteromedial, and posterolateral reach directions.

on their hips. To record a measurement, the participant needed to reach with one lower extremity as far as possible in the appropriate direction and return to center without any loss of balance. Each participant was allowed four practice attempts in each direction before any measurements were recorded.^{21,29} Three trials were performed in a randomized order and the average of three trials in each direction was used for data analysis. A SEBT composite score was also determined by averaging the three reach directions. Reach distances were normalized to limb length (anterior superior iliac spine to the ipsilateral distal medial malleolus).³⁰ Intersession reliability for the three reach directions of the SEBT has been described as good ($ICC_{2,1} = .74$ to $.92$) for individuals with CAI.³¹ The anterior reach direction demonstrates the best reliability ($ICC_{2,1} = .92$), while the posteromedial ($ICC_{2,1} = .86$) and posterolateral ($ICC_{2,1} = .74$) directions have lower reliability estimates. The minimal detectable change for SEBT normalized reach distances has been previously established: anterior (1.8%), posteromedial (3.2%), and posterolateral (5.3%).³²

Data Analysis

Linear regression was used to determine the relationship (r) and explained variance (r^2) between ankle dorsiflexion ROM and SEBT anterior, posteromedial, and posterolateral normalized reach distances and composite SEBT scores. Relationships were interpreted as follows: little or no relationship ($r = 0.0$ - 0.25), fair relationship ($r = 0.25$ - 0.50), moderate to good relationship (0.50 - 0.75), good to excellent relationship ($r > 0.75$).³³ The alpha level was set *a priori* at $P \leq 0.05$ and all statistical analyses were performed with SPSS Version 19.0 (SPSS Inc., Chicago, IL).

RESULTS

Point estimates and standard deviations for the measures are as follows: dorsiflexion ROM ($41.3^\circ \pm 7.9^\circ$), anterior reach ($64.4 \pm 6.0\%$), posteromedial reach ($78.7 \pm 8.9\%$), posterolateral reach ($69.1 \pm 9.7\%$), and the composite SEBT score ($70.8 \pm 6.7\%$). There were fair positive correlations between dorsiflexion ROM and the anterior reach direction ($r = .55$, $r^2 = .31$, $P < .001$) (Figure 3a), posterolateral reach direction ($r = .29$, $r^2 = .09$, $P = .03$) (Figure 3c) and the composite SEBT scores ($r = .30$, $r^2 = .09$, $P = .02$) (Figure 3d). There was little or no relationship between ankle dorsiflexion and the posteromedial reach direction ($r = .01$, $r^2 = .001$, $P = .47$) (Figure 3b).

DISCUSSION

The purpose of this study was to determine the relationship between a weight-bearing measure of ankle dorsiflexion ROM and dynamic balance measured using the SEBT in participants with CAI. The results indicate that there was a significant positive relationship between ankle dorsiflexion ROM and dynamic balance measures in participants with CAI. Ankle dorsiflexion ROM had the strongest relationship ($r = .55$) with the anterior reach direction of the SEBT and explained 31% of the variance in reach distance which indicates that mechanical impairments in ankle motion can impact dynamic function during a balance task.

Visual examination during performance of the SEBT reach directions indicates the anterior reach component requires the most ankle dorsiflexion in comparison to the other reach directions. In this study ankle dorsi-

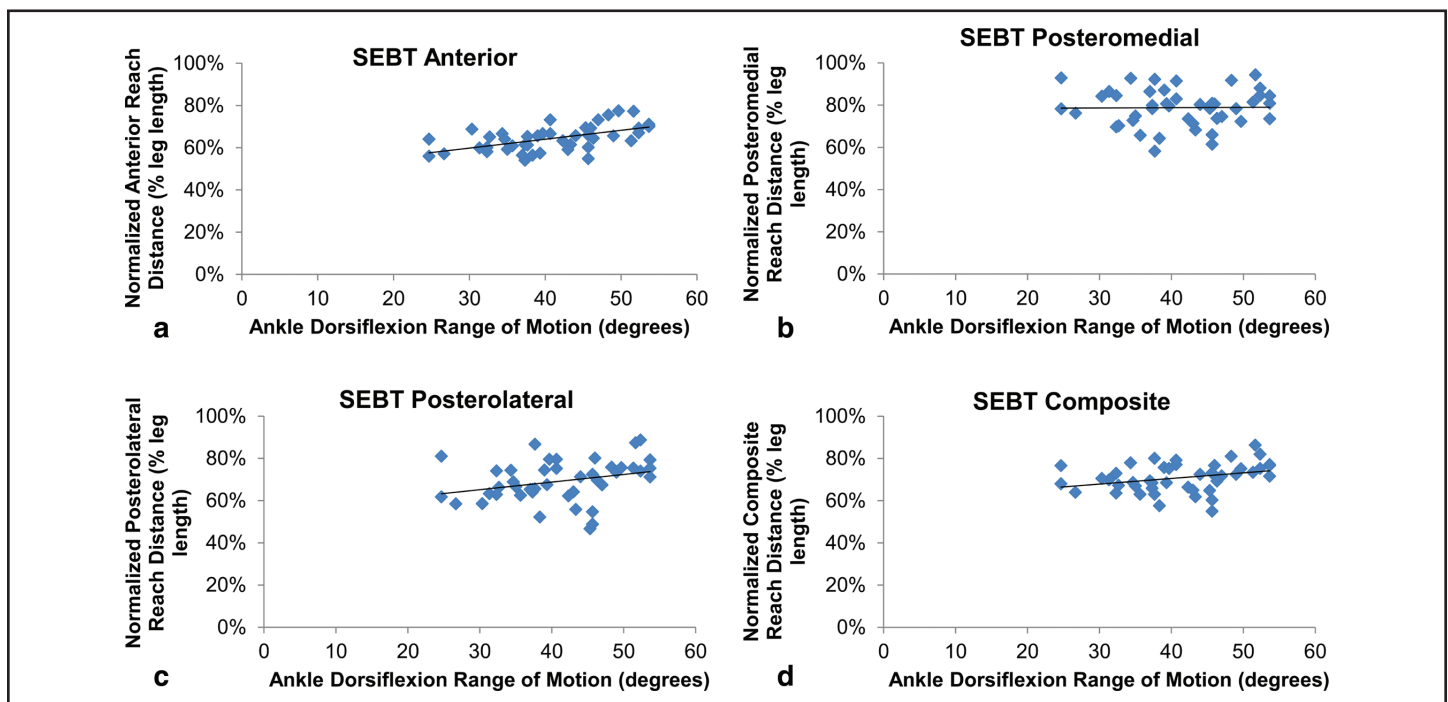


Figure 3. Scatter plots for ankle dorsiflexion range of motion and a) anterior reach, b) posteromedial reach, c), posterolateral reach, and d) composite SEBT scores. Ankle dorsiflexion range of motion is expressed in degrees and reach distances are expressed as a percentage of leg length.

flexion ROM was able to explain 31% of the variance in the anterior reach distance, which is slightly greater than previously reported explained variance estimates of 22% in individuals with CAI.¹⁷ Clinically this highlights the importance of adequate ROM for dynamic tasks in individuals with ankle pathology. Furthermore, the current results indicate there is also a relationship, although small (9% of variance explained), with the posterolateral reach direction and composite SEBT scores. The clinical relevance of these measure relationships is likely minimal and may also be due to the calculation method of the composite score as it incorporates reach distances in all three test directions.

Although weight-bearing ankle dorsiflexion ROM has been shown to contribute to dynamic balance in this study and others,^{17,21} it is not the only contributing factor. There was still a large portion of the variance in reach distances that could not be explained by ankle dorsiflexion ROM. Motion and neuromuscular control of the lower extremity also likely contribute to SEBT reach distances. Strength of the hip musculature³⁴ and hip and knee flexion motion²⁰ have been shown to have strong relationships with SEBT reach distances,

particularly in the posteromedial and posterolateral directions. A limitation of this study was that measures of ROM or strength at other joints were not obtained and to date no study has concurrently investigated the kinematic contributions of the entire lower extremity to reach distances during the SEBT.^{15,16,28}

The amount of ankle dorsiflexion ROM has been shown to affect a number of dynamic activities. Ankle dorsiflexion ROM has been shown to affect jogging mechanics²² and landing mechanics³⁵ in individuals with CAI, balance in older individuals,³⁶ and squat^{37,38} and step³⁹ biomechanics in healthy individuals. Limitations in ankle dorsiflexion have also been shown to be a risk factor for lower extremity⁴⁰ and knee joint pathology⁴¹⁻⁴³. Additionally an asymmetry between right and left anterior reach distances (>4 cm)¹⁸ and limitations in posterolateral reach distances (<80% normalized reach distance)¹⁹ have been shown to be a risk factors for lateral ankle sprains. This may be a contributing factor for recurrent ankle sprains experienced by individuals with CAI. It is possible that impairments in ankle dorsiflexion ROM may concurrently contribute to decreased anterior reach distance and elevated injury risk.

Although the results of this study begin to provide insights into the relationship between measures of ROM and dynamic balance, an additional limitation was that the participants in this study were relatively young (23.2 ± 2.8 y) and met specific criteria indicative of CAI (FAAM Sport ≤ 85 and AII ≥ 3). Additionally the authors did not attempt to quantify mechanical instability due to ligamentous insufficiency. The results of this study may not be generalized to individuals outside of this specific demographic such as older adults or individuals with other lower extremity pathologies.

Future studies should determine if interventions directed at improving ankle dorsiflexion ROM have an immediate impact on dynamic balance. Preliminary evidence suggests that a 2 week intervention program that includes talocrural joint mobilization can improve ankle dorsiflexion ROM and SEBT reach distances.⁴⁴ Since a number of impairments contribute to CAI comprehensive intervention strategies are likely necessary to reduce recurrence rates of lateral ankle sprains and improve function. Programs that aim to address CAI and reduce ankle sprain injury risk are typically multifaceted and include external support and neuromuscular training.⁴⁵⁻⁴⁷ Based on the results of this study it appears that there is a subset of individuals with CAI that demonstrate impairments in ankle dorsiflexion ROM and SEBT anterior reach distances who may benefit from interventions such as stretching or joint mobilization. Additional studies are needed to better identify subsets of patients who would benefit from specific intervention programs.

CONCLUSIONS

Available motion at the ankle, specifically dorsiflexion ROM, contributes to dynamic balance measures. Individuals with CAI who demonstrate impairments in dorsiflexion may also demonstrate difficulty with portions of the SEBT. Studies have shown that the SEBT can be used in a pre-participation screening to identify individuals who are at increased risk for lower extremity injuries. Clinicians may use this information to better optimize rehabilitation programs that address ankle dorsiflexion ROM and dynamic balance. Concurrently, screening ankle dorsiflexion ROM can provide insight into performance on the SEBT, and subsequently provide insights regarding the individual risk of injury.

REFERENCES

1. van Rijn RM, van Os AG, Bernsen RMD, Luijsterburg PA, Koes BW, Bierma-Zeinstra SMA. What is the clinical course of acute ankle sprains? A systematic literature review. *Am J Med.* 2008;121(4):324-331.
2. Hertel J. Functional instability following lateral ankle sprain. *Sports Med.* 2000;29(5):361-371.
3. Holmes A, Delahunt E. Treatment of common deficits associated with chronic ankle instability. *Sports Medicine.* 2009;39(3):207-224.
4. Olmsted LC, Carcia CR, Hertel J, Shultz SJ. Efficacy of the Star Excursion Balance Test in detecting reach deficits in subjects with chronic ankle instability. *J Athl Train.* 2002;37(4):501-506.
5. Gribble PA, Hertel J, Denegar CR, Buckley WE. The effects of fatigue and chronic ankle instability on dynamic postural control. *J Athl Train.* 2004;39(4):321-329.
6. Hertel J, Braham RA, Hale SA, Olmsted-Kramer LC. Simplifying the Star Excursion Balance Test: Analyses of subjects with and without chronic ankle instability. *J Orthop Sports Phys Ther.* 2006;36(3):131-137.
7. Hertel J. Functional anatomy, pathomechanics, and pathophysiology of lateral ankle instability. *J Athl Train.* 2002;37(4):364-375.
8. Hiller CE, Kilbreath SL, Refshauge KM. Chronic ankle instability: Evolution of the model. *J Athl Train.* 2011;46(2):133-141.
9. de Noronha M, Refshauge KM, Crosbie J, Kilbreath SL. Relationship between functional ankle instability and postural control. *J Orthop Sports Phys Ther.* 2008;38(12):782-789.
10. Docherty CL, Valovich McLeod TC, Shultz SJ. Postural control deficits in participants with functional ankle instability as measured by the Balance Error Scoring System. *Clin J Sport Med.* 2006;16:203-208.
11. Riemann BL. Is there a link between chronic ankle instability and postural instability? *J Athl Train.* 2002;37(4):386-393.
12. Wikstrom EA, Fournier KA, McKeon PO. Postural control differs between those with and without chronic ankle instability. *Gait Posture.* 2010;32(1):82-86.
13. McKeon PO, Hertel J. Spatiotemporal postural control deficits are present in those with chronic ankle instability. *BMC Musculoskelet Disord.* 2008;9:76.
14. McKeon PO, Hertel J. Systematic review of postural control and lateral ankle instability, Part I: Can deficits be detected with instrumented testing. *J Athl Train.* 2008;43(3):293-304.

-
15. Arnold BL, De La Motte S, Linens S, Ross SE. Ankle instability is associated with balance impairments: A meta-analysis. *Med Sci Sports Exerc.* 2009;41(5):1048-1062.
 16. Kinzey SJ, Armstrong CW. The reliability of the Star Excursion Balance Test in assessing dynamic balance. *J Orthop Sports Phys Ther.* 1998;27(5):356-360.
 17. Hoch MC, Staton GS, Medina McKeon JM, Mattacola CG, McKeon PO. Dorsiflexion and dynamic postural control deficits are present in those with chronic ankle instability. *J Sci Med Sport.* 2012;15(6):574-579.
 18. Plisky PJ, Rauh M, Kaminski T, Underwood F. Star Excursion Balance Test as a predictor of lower extremity injury in high school basketball players. *J Orthop Sports Phys Ther.* 2006;36:911-919.
 19. de Noronha M, França LC, Haupenthal A, Nunes GS. Intrinsic predictive factors for ankle sprain in active university students: A prospective study. *Scand J Med Sci Sports.* 2012; doi: 10.1111/j.1600-0838.2011.01434.x.
 20. Robinson R, Gribble P. Kinematic predictors of performance on the Star Excursion Balance Test. *J Sport Rehabil.* 2008;17(4):347-357.
 21. Hoch M, Staton G, McKeon PO. Dorsiflexion range of motion significantly influences dynamic balance. *J Sci Med Sport.* 2011;14:90-92.
 22. Drewes LK, McKeon PO, Kerrigan DC, Hertel J. Dorsiflexion deficit during jogging with chronic ankle instability. *J Sci Med Sport.* 2009;12(6):685-687.
 23. Martin RL, Irrgang JJ, Burdett RG, Conti SF, Van Swearingen JM. Evidence of validity for the Foot and Ankle Ability Measure (FAAM). *Foot Ankle Int.* 2005;26(11):968-983.
 24. Docherty C, Gansneder B, Arnold B, Hurwitz S. Development and reliability of the ankle instability instrument. *J Athl Train.* 2006;41(2):154-158.
 25. Bennell KL, Talbot RC, Wajswelner H, Tschovanich W, Kelly DH, Hall AJ. Intra-rater and inter-rater reliability of a weight-bearing lunge measure of ankle dorsiflexion. *Aust J Physiother.* 1998;44(3):175-180.
 26. Denegar CR, Hertel J, Fonseca J. The effect of lateral ankle sprain on dorsiflexion range of motion, posterior talar glide, and joint laxity. *J Orthop Sports Phys Ther.* 2002;32(4):166-173.
 27. Vicenzino B, Branjerdporn M, Teys P, Jordan K. Initial changes in posterior talar glide and dorsiflexion of the ankle after mobilization with movement in individuals with recurrent ankle sprain. *J Orthop Sports Phys Ther.* 2006;36(7):464-471.
 28. Konor MM, Morton S, Eckerson JM, Grindstaff TL. Reliability of three measures of ankle dorsiflexion range of motion. *Int J Sports Phys Ther.* 2012;7(3):1-9.
 29. Robinson RH, Gribble PA. Support for a reduction in the number of trials needed for the Star Excursion Balance Test. *Arch Phys Med Rehabil.* 2008;89(2):364-370.
 30. Gribble PA, Hertel J. Considerations for normalizing measures of the Star Excursion Balance Test. *Meas Phys Ed Ex Sci.* 2003;7:89-100.
 31. Hoch MC, Stanton GS, McKeon PO. Reliability and responsiveness of the Star Excursion Balance Test in those with chronic ankle instability. *Med Sci Sports Exerc.* 2010;42(5):492-493.
 32. Hoch M, McKeon PO. Joint mobilization improves spatiotemporal postural control and range of motion in those with chronic ankle instability. *J Orthop Res.* 2011;29(3):326-332.
 33. Portney LG, Watkins MP. *Foundations of Clinical Research: Applications to Practice.* 3rd ed. Upper Saddle River, NJ: Pearson Prentice Hall; 2009.
 34. Hubbard TJ, Kramer LC, Denegar CR, Hertel J. Correlations among multiple measures of functional and mechanical instability in subjects with chronic ankle instability. *J Athl Train.* 2007; 42(3):361-366.
 35. Delahunt E, Monaghan K, Caulfield B. Changes in lower limb kinematics, kinetics, and muscle activity in subjects with functional instability of the ankle joint during a single leg drop jump. *J Orthop Res.* 2006;24(10):1991-2000.
 36. Mecagni C, Smith JP, Roberts KE, O'Sullivan SB. Balance and ankle range of motion in community-dwelling women aged 64 to 87 years: A correlational study. *Phys Ther.* 2000;80(10):1004-1011.
 37. Macrum E, Bell DR, Boling M, Lewek M, Padua D. Limiting ankle dorsiflexion range of motion alters lower extremity kinematics and muscle activation patterns during a squat. *J Sport Rehabil.* 2012;21(2):144-150.
 38. Fong C, Blackburn JT, Norcross MF, McGrath M, Padua DA. Ankle-dorsiflexion range of motion and landing biomechanics. *J Athl Train.* 2011;46(1):5-10.
 39. Rabin A, Kozol Z. Measures of range of motion and strength among healthy women with differing quality of lower extremity movement during the lateral step-down test. *J Orthop Sports Phys Ther.* 2010;40(12):792-800.
 40. Pope R, Herbert R, Kirwan J. Effects of ankle dorsiflexion range and pre-exercise calf muscle stretching on injury risk in Army recruits. *Aust J Physiother.* 1998;44(3):165-172.
 41. Malliaras P, Cook JL, Kent P. Reduced ankle dorsiflexion range may increase the risk of patellar tendon injury among volleyball players. *J Sci Med Sport.* 2006;9(4):304-309.
-

-
42. Gross MT, Foxworth JL. The role of foot orthoses as an intervention for patellofemoral pain. *J Orthop Sports Phys Ther.* 2003;33(11):661-670.
 43. Witvrouw E, Lysens R, Bellemans J, Cambier D, Vanderstraeten G. Intrinsic risk factors for the development of anterior knee pain in an athletic population. A two-year prospective study. *Am J Sports Med.* 2000;28:480-489.
 44. Hoch MC, Andreatta RD, Mullineaux DR, et al. Two-week joint mobilization intervention improves self-reported function, range of motion, and dynamic balance in those with chronic ankle instability. *J Orthop Res.* 2012;30(11):1798-1804.
 45. Verhagen EALM, Bay K. Optimising ankle sprain prevention: A critical review and practical appraisal of the literature. *Br J Sports Med.* 2010;44(15):1082-1088.
 46. Dizon JM, Reyes JJ. A systematic review on the effectiveness of external ankle supports in the prevention of inversion ankle sprains among elite and recreational players. *J Sci Med Sport.* 2010;13(3):309-317.
 47. van der Wees PJ, Lenssen AF, Hendriks EJ, Stomp DJ, Dekker J, de Bie RA. Effectiveness of exercise therapy and manual mobilisation in ankle sprain and functional instability: A systematic review. *Aust J Physiother.* 2006;52(1):27-37.